TESTING OF A VISCOUS-DAMPED ISOLATOR

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ABSTRACT

It is essential that accurate methods for testing mechanical properties be employed during the development of precision spacecraft isolation systems. Mechanical properties of the isolator will determine force transmission to the spacecraft; thus they are critical to its performance. This paper documents component-level tests performed on viscous-damped isolators developed by Honeywell Satellite Systems for a spacecraft reaction wheel isolator system.

Two types of component-level tests were performed on the elements: direct stiffness measurements (often called mechanical impedance) and transmissibility tests. Direct stiffness measurements indicated linearity, linear stiffness, damping, and hysteresis. A custom test apparatus was designed for accuracy and repeatability. Stiffness deviations as small as 5 percent could be detected, and loss factors as low as 0.01 could be resolved with the direct stiffness measurements.

Motion transmissibility measurements determined high-frequency isolation and verified stiffness and damping near the predicted resonance of the sprung payload. Although the suspension system consisted of eight isolators, tests were performed on a single unit. Motion was constrained to a single degree of freedom using a system of air bearings sliding on rails. The air bearing design possessed less than 0.4 grams of friction allowing verification of isolation properties to above 300 Hz and enabled transmissibility to be accurately measured over 4 orders-of-magnitude of input excitation.

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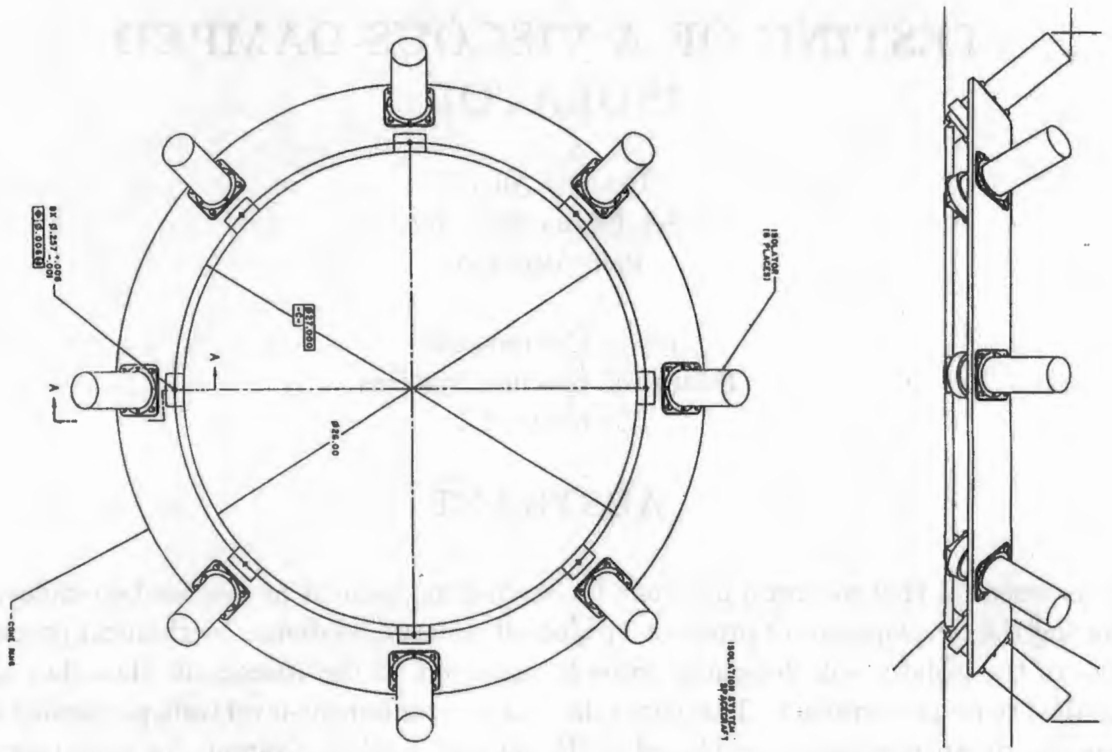


Figure 1. Reaction wheel isolation system

1. Introduction

Viscous damper designs are finding wider applications in spacecraft; demands for lower ambient vibration levels coupled with the predictability and simplicity of viscous dampers make them a good choice for many damping applications in space. This paper addresses test techniques used to characterize the mechanical properties of an isolation system by testing its components: viscous-damped isolators.

The isolators are used to suspend the momentum wheel on a spacecraft. The suspension consists of eight isolators placed symmetrically around the frame of the momentum wheel, as shown in Figure 1. Machined metal springs provide elastic forces with nearly isotropic stiffness, but the damping mechanism applies dissipative forces primarily along the element's axis. These isolators are designed to behave with a linear force-deflection relationship and an axial stiffness of approximately 950 lbf/in up to a stroke limit of 0.044 inches. Mechanical stops dramatically increase the stiffness outside this operational region.

Isolation performance was specified for the system to tolerances that required repeatable and predictable mechanical performance. Transmissibility was specified to 300 Hz, such that modes introduced by the isolators could not obstruct the transmissibility below 300 Hz.

2. Test Method

Tests documented in this paper were performed at the component level. Component or element level testing provides detailed characterization data such as linearity, hysteresis, damping variation with excitation levels and temperature, and other variations in mechanical performance between isolators. Measurements of both axial and radial properties were made. Component-level tests were performed to acquire data necessary for the design of the isolators, and system-level tests subsequently verified that component-level test results could be extrapolated to system level performance.

Two approaches were implemented at the component level: direct complex stiffness (DCS) methods and resonant tests. DCS methods use the force through and displacement across a specimen to calculate the complex stiffness of a specimen directly at frequencies well below the resonances of the test assembly. Under this condition, the elastic stiffness is the real part of the ratio between force and displacement, and damping is calculated from their phase difference. Resonant tests infer the mechanical properties of a resonant system through an analytical model where modal frequencies and damping ratios are inputs, and specimen stiffness and damping are outputs. A single-degree of freedom system was constructed for these tests with a one-eighth-scale mass sprung on one of the eight isolators. The ratio of acceleration across the masses was measured to construct a dimensionless function of frequency known as transmissibility.

DCS tests yielded the majority of the mechanical property data on the isolators. A DCS test assembly was designed which could measure the unidirectional mechanical properties in both the axial and radial directions of the isolator. Figure 2 shows the test assembly for the axial configuration. Motion was constrained to one degree-of-freedom by the pushrod and linear bearings. Measurement bandwidth of the assembly was from DC to 96 Hz, limited on the high end by the resonant frequency of the isolator and sprung fixture.

Transmissibility tests verified high frequency isolation, enabled testing over a wide dynamic range, and provided verification of stiffness and damping at a single frequency for verification of the DCS test results. Isolation performance at high frequency was verified by continuation of transmissibility roll off with increasing frequency.

Transmissibility measurements utilized a test assembly that simulated a single-degree of freedom system. It restricted motion across the isolator to one direction without exerting forces in the unconstrained direction. Figure 3 shows the apparatus while outfitted for axial measurements. The center mass floats on the rails through air bearings. Two center masses were designed for the radial and axial test configurations. The rails and external mass simulate a rigid massive mounting base which translates to provide unidirectional excitation. Transmissibility is measured along the axes of the rails, and is calculated as the ratio of the acceleration seen at the floating mass to that at the base. The center mass was sized to one-eighth that of the system level, since only one of eight isolators was under test at any instant in the component-level tests.

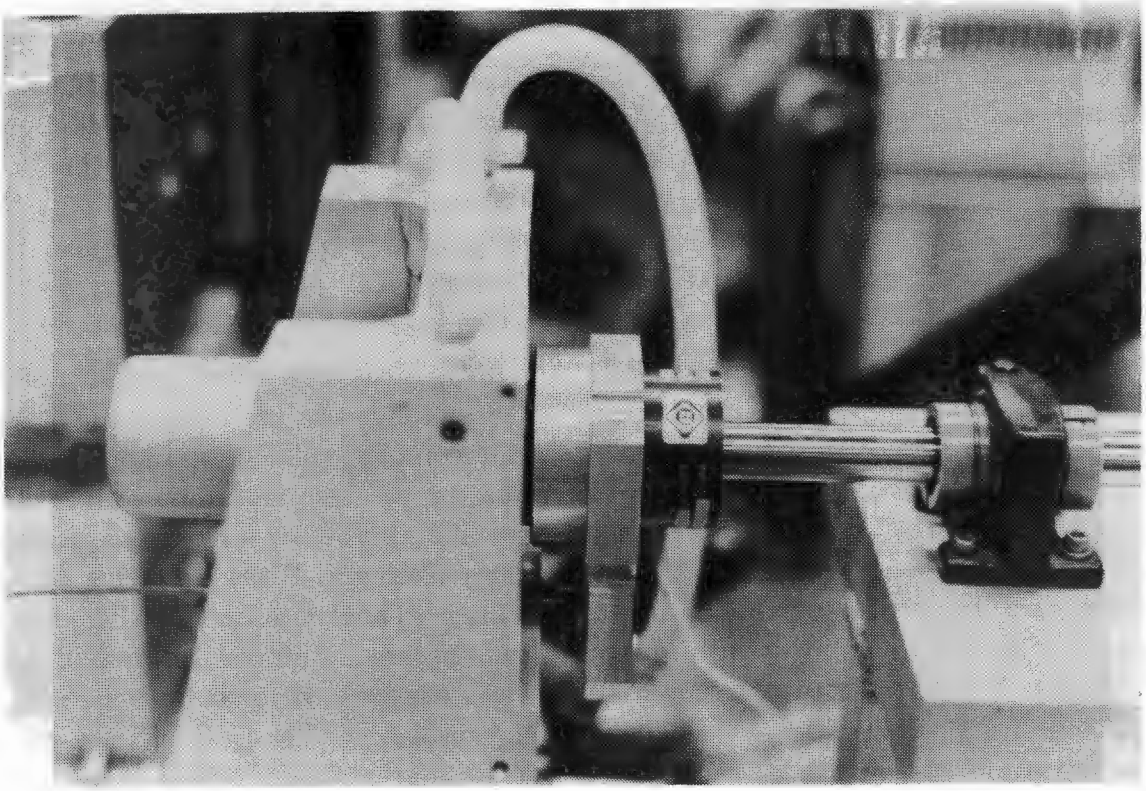


Figure 2. DCS test assembly in the axial configuration

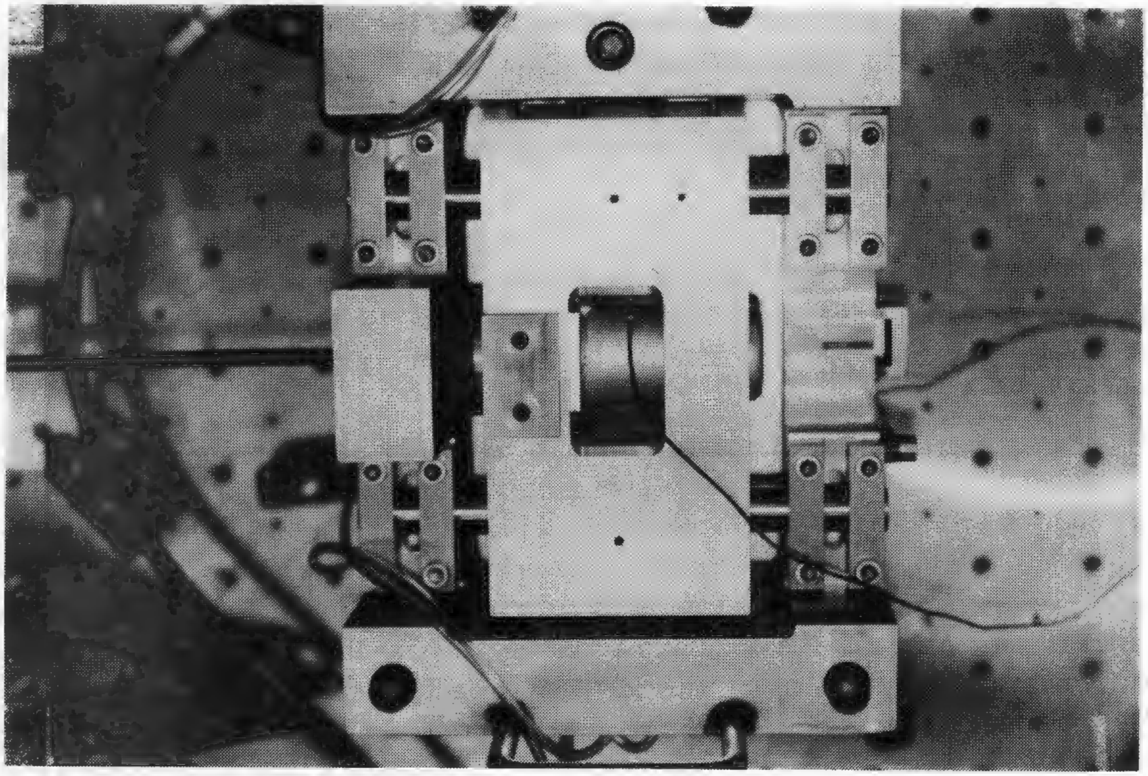


Figure 3. Transmissibility test assembly in the axial configuration

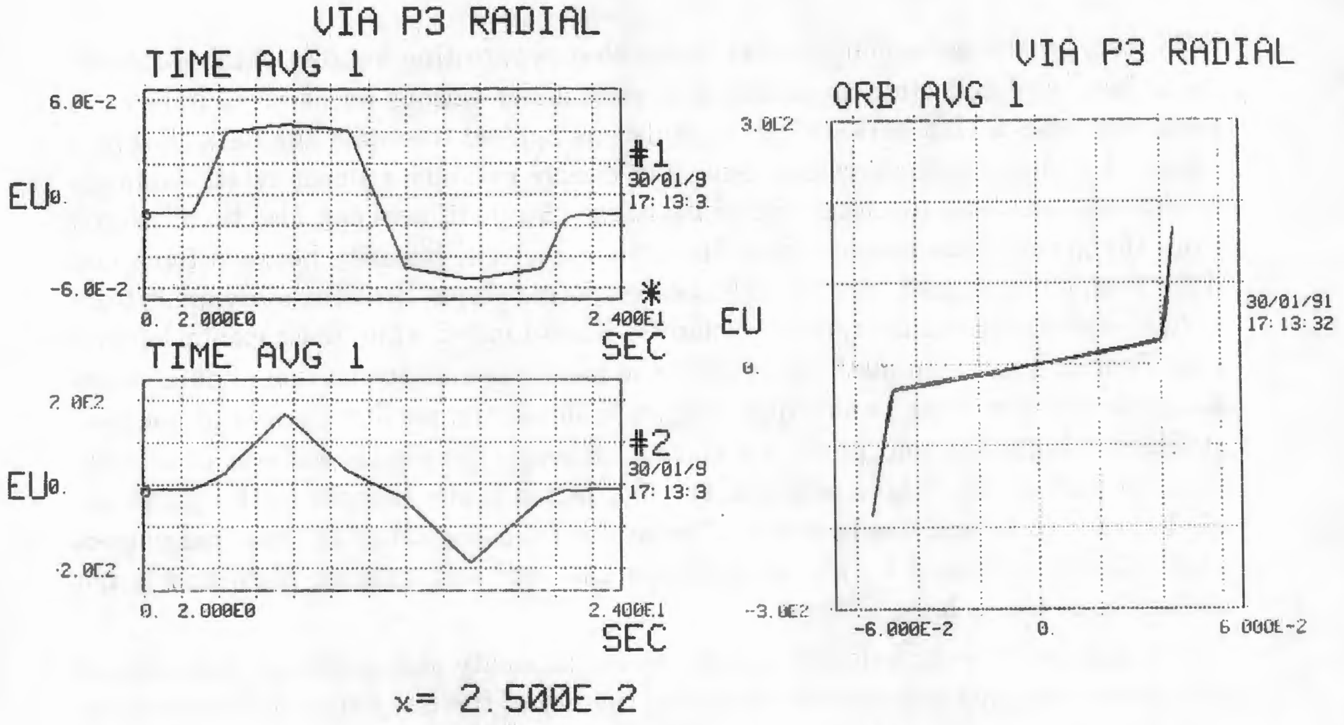


Figure 4. Pseudo-static DCS test data.

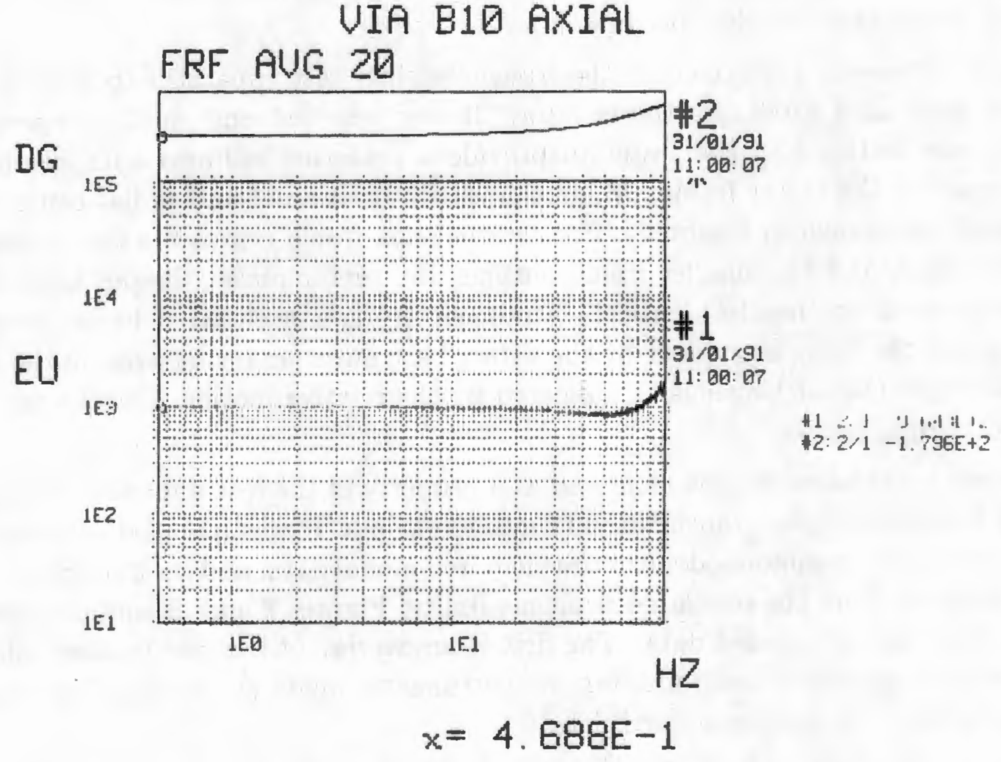


Figure 5. Dynamic DCS test data.

3. Results

DCS tests proved particularly useful for development testing because of the availability of force and deflection as functions of time under various forms of excitation. A sawtooth wave with a period of 20 seconds was applied to obtain the data shown in Figure 4. The plot force versus deflection clearly exhibits a linear relationship up to the stop locations at either end of its stroke. Stop stiffness can also be measured from the graph. One measurement identifies hysteresis, linearity between force and deflection, stiffness, and location of travel restricting stops. Broadband dynamic tests indicated stiffness and damping of isolators. Band-limited white noise excitation and Fast-Fourier Transform methods enabled the instantaneous acquisition of data across an entire measurement bandwidth. Figure 5 shows the resulting curve of complex stiffness. Magnitude and phase are shown, although the elastic stiffness is actually the real part of the magnitude, and the loss factor is the tangent of the phase angle between force and displacement. Deviations from constancy of these parameters above 30 Hz is caused by the mass of the load cell and adapter plate and is not indicative of the isolator stiffness.

Transmissibility data demonstrated the repeatability and precise performance of the viscous damped isolators; however, the rigidity of the test fixture fell short of the specifications requiring a bandwidth of 300 Hz. A sizeable mode appeared to obstruct isolation of the system near 300 Hz. Figure 6 shows a typical transmissibility plot as measured. The base mass was supported on flexures to permit unidirectional motion, and tests mentioned below indicated that an extensional mode of the flexures was partially responsible for the obstruction.

Modal tests were performed on the transmissibility test apparatus to identify the harmful mode and exonerate the isolator. It was removed and small compression springs were installed in the tester to provide a centering stiffness with negligible added mass to the tester frame. Mode shapes for both axial and radial tester configurations are shown in Figure 7. The external box frame represents the outline of the base mass, and the smaller frame outlines the center mass. Shapes from axial and radial tests are nearly identical. Strain energy is concentrated in the flexures that support the base, as evident by the tilting base mass, and somewhat in the flexible mounts of the air bearings as indicated by the relative motion between the two apparently rigid bodies.

The detrimental mode was identified as a property of the test apparatus and subtracted from subsequent transmissibility measurements. It was modeled as a second-order system as is commonly done in test-acquired modal data, and its transmissibility was subtracted from the measured transmissibility. Figures 8 and 9 contain plots of the pre- and post-processed data. The first is an overlay of the raw transmissibility curve and the generated response for the detrimental mode at 280 Hz. Figure 9 is their difference, the post-processed data.

The viscous damped isolators operate in a low-level vibration environment, and tests were performed to verify linearity across a range of excitation levels. Limitations in the test apparatus and instrumentation limited measurements of dynamic range to

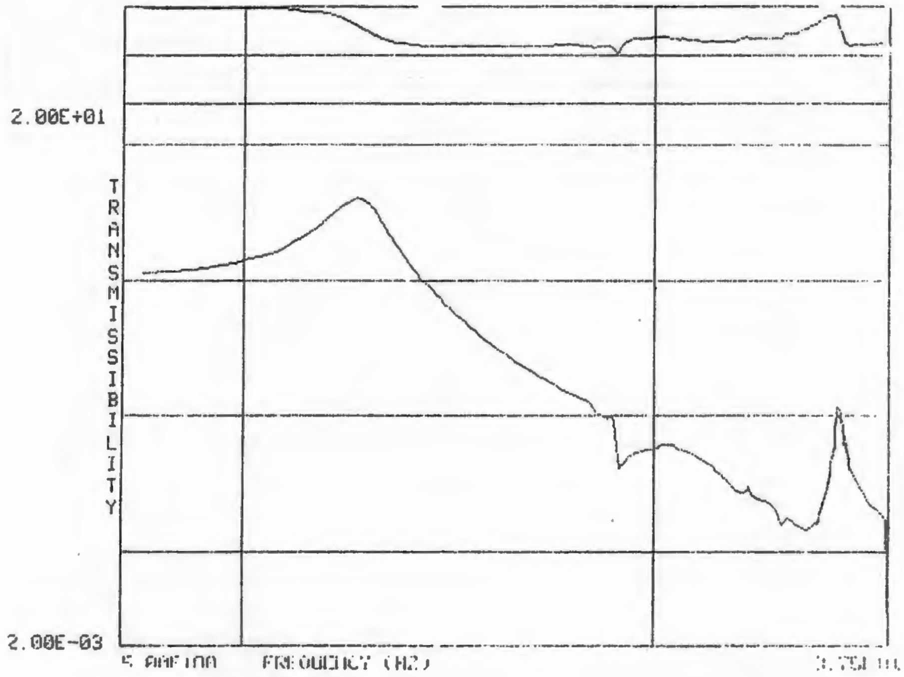
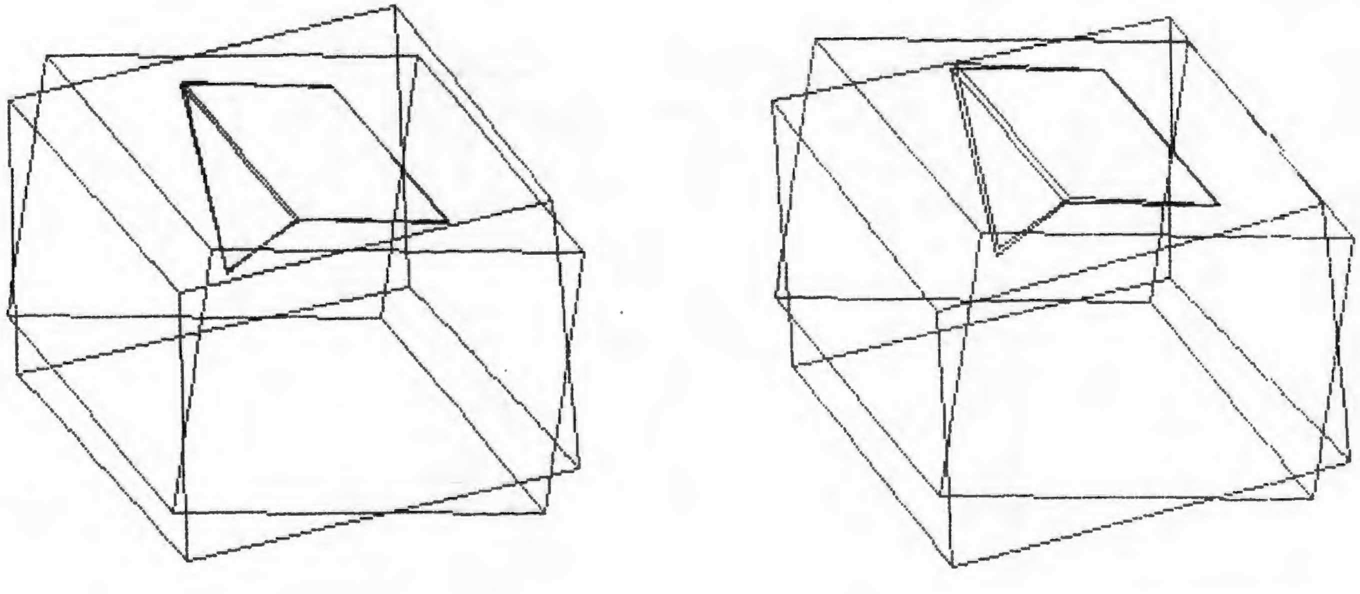


Figure 6. Unprocessed transmissibility data in axial configuration.



Axial Configuration

Radial Configuration

Figure 7. Mode shapes of detrimental resonance for axial and radial test configurations.

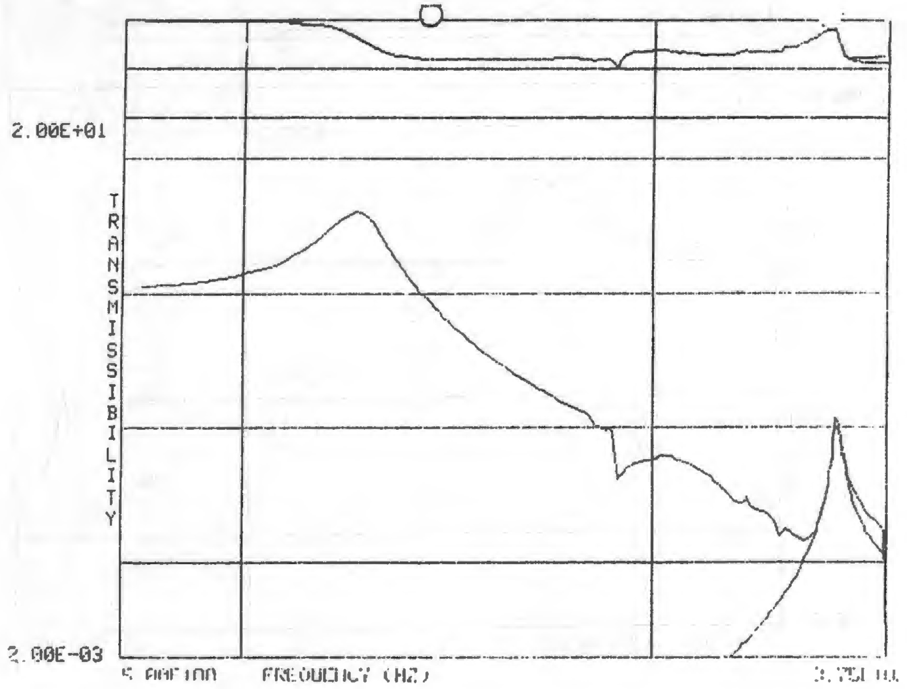


Figure 8. Unprocessed transmissibility overlayed with synthesis of reconstructed mode.

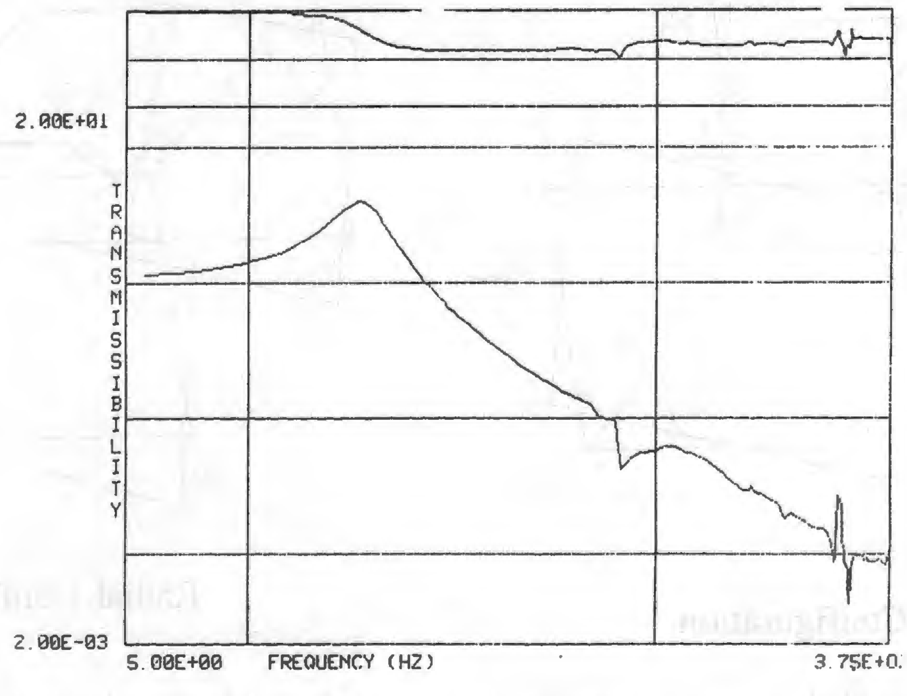


Figure 9. Post-processed transmissibility data.

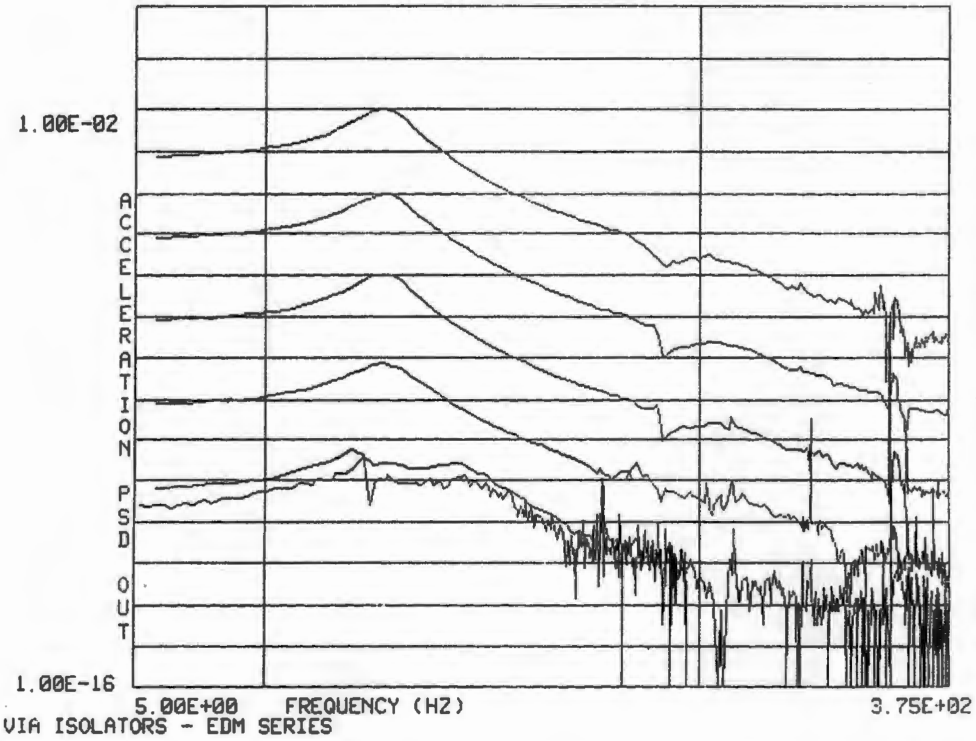


Figure 10. Acceleration Power Spectral Density of Isolated Mass for White Noise Excitation

90 dB, from 25 micro-Gs to 1.5 Gs rms. Figure 10 is a plot of the output acceleration PSD for a white noise input from 1 to 375 Hz. Because white noise is a constant level, the character of the curve is identical to the corresponding transmissibility function at each level. At base acceleration levels of 50 micro-Gs rms and below (lowest level curve), a subtle changes in the shape of the transmissibility function became apparent, and a limited amount of troubleshooting tests were performed. They indicated that restoration force well below 0.04 lbs was being introduced by the tester assembly and is related to the air pressure in the air bearings. Since this level was below the required specifications for the isolator, it was not pursued further.

4. Summary and Conclusions

Component level tests provided accurate characterization of the mechanical properties of the viscous damped isolators. DCS tests were most effective for verification of linearity, static force-deflection information, and stiffness and damping properties at frequencies well below that of the DCS test assembly. Resonant methods proved more effective for examination of the roll off in transmissibility at high frequency and for acquiring data across a wide dynamic range of input excitation levels.

Tests indicated that the viscous damped isolators performed as predicted, with repeatable and precise mechanical properties. They behaved linearly from 25 micro-Gs to 1.5 Gs, with precise stiffness and damping properties.